ANAGEMENT OF MOIST-SITE VEGETATION FOR WATER

PAST HISTORY, PRESENT STATUS AND FUTURE NEEDS

1976

MANAGEMENT OF MOIST-SITE VEGETATION FOR WATER: PAST HISTORY, PRESENT STATUS, AND FUTURE NEEDS

By

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PREFACE

The information upon which to develop management plans for Southwestern wildlands, considering all resources, has greatly increased in the last few decades but many unanswered questions still remain concerning optimum prescriptions for action. The Pacific Southwest Inter-Agency Committee (PSIAC) and its former Phreatophyte Subcommittee have played a vital role in the accumulation and dissemination of information in regard to management for water quantity and quality.

The PSIAC at their 73-3 meeting requested the Vegetation Management Technical Subcommittee to prepare a summary report on the state of the art of watershed management and salvage techniques. In response to this request, the following report has been prepared. It outlines:

1. The history of research leading to the buildup of knowledge in the field of land management as applied to water. The shift from considering forests and other vegetation as "producers of water" to the realization that they are "users of water" and that proper reduction of cover can increase water yield without causing floods or destruction of other resources will be discussed. The Phreatophyte Subcommittee was never given the responsibility of coordination and review of the many research and action programs in the forest, woodland, and chaparral types. Thus, this report will limit its discussion of these types to listing the recent "state-of-the-art" reports and certain other pertinent publications that amply summarize past research and present status of the knowledge concerning these vegetation zones. In contrast, the moist-site zones will be covered in detail.

2. The application of past research results and observations in the phreatophyte and riparian zones. The present knowledge about these types of vegetation and their management will be discussed in full, with a listing of pertinent literature. The role of such interagency groups as the Phreatophyte Subcommittee will be emphasized.

3. The pressing need for further research and evaluation of present conditions in wildland vegetation management, emphasizing moist-site zones. The present Vegetation Management Technical Subcommittee (an outgrowth of the Phreatophyte Subcommittee), however, covers all types in respect to management for water quantity and quality and the effect of such practices on other resources. The place of the Subcommittee as a coordinator of the activities of the various Federal and State agencies will be stressed.

HISTORY OF VEGETATION MANAGEMENT FOR WATER

Little attention was paid to wildland vegetation management during the pioneer exploitation period when natural resources such as dense forests were often a detriment to development rather than a value. Shortly before the turn of the century, effects of forest and range denudation became apparent since it was often followed by floods and increased erosion. Early conservation efforts were focused on these factors. Research in the main (what little there was) was aimed at measuring these effects of removal of vegetation.

Forests were assumed to increase water flow partly by increasing precipitation and partly by reducing floodflows and releasing this water over a longer period. Transpiration losses were recognized as minimal but were felt to increase rainfall (Zon 1927). The Emmenthal watersheds, established in Europe in 1903 (Penman 1963), and the Wagon Wheel Gap study in Colorado in 1910 (Bates and Henry 1928), demonstrated that removal of a forest cover increased total flow of water and might be desirable where sufficient vegetation remained to prevent erosion. These results remained obscure until Hoyt and Troxell (1932) suggested that removal of watershed vegetation, even by fire, might be a desirable practice where water shortages were being felt and where erosion could be reduced or controlled. The resulting controversy sparked many research programs and opened the way for a new approach to vegetation management, even though many of the experimental watersheds were designed to demonstrate only the deleterious effects of fire and overuse of vegetation rather than an objective evaluation of the many factors involved. In California, destructive floods from fire-denuded watersheds shifted the emphasis to site stabilization because water shortages were not as feared after arrival of Colorado River water and a series of moist years. However, by the late '40's the great increase of water demand due to drought years and increase of population placed the emphasis again on the management of watersheds and floodplains for water yield (Lassen, Lull, and Frank 1952).

Interest in water losses from flood-plain vegetation had stimulated research in southern California by 1927 (California Division of Water Resources 1930). Measurements of water loss from mountain riparian vegetation started soon after (Taylor and Nickle 1933b and Young and Blaney 1942).

This increased interest in the effect of forests and other woody vegetation upon water yield, floods, and erosion created many research projects, including ambitious watershed, plot, and tank studies throughout the United States. While earlier watersheds had been established on a small scale in Utah and California, major projects were started on a more ambitious scale in the early 1930's in Arizona, California, and Colorado. Publications discussing these various research studies were abstracted by Horton (1973). Hibbert (1965) analyzes the results of the various treatments on watersheds throughout the world.

In Arizona the very critical water shortages and the increase of brush and forest vegetation due to prolonged protection from fires, created a desire to instigate a major action program of vegetation reduction and increased research. This stimulated the formation of the Arizona Watershed Program and the preparation of an extensive evaluation report by the University of Arizona (Barr 1956).

Starting in 1974, a cooperative effort by the University of Arizona Department of Watershed Management, the Arizona Watershed Commission, and the Rocky Mountain Forest and Range Experiment Station (U.S. Forest Service) has carried on an extensive evaluation of the watershed situation and made estimations of the amounts of water saved by reducing vegetation and the effects of such programs on other resources. These efforts culminated in a voluminous report by Ffolliott and Thorud (1975). This report is summarized by the same authors (1974). The Rocky Mountain Station, as part of the cooperative effort, prepared a series of comprehensive review reports for each of the main vegetation types in which they have carried on research: Mixed conifer (Rich and Thompson 1974), ponderosa pine (Brown and others 1974), pinyon-juniper (Clary and others 1974), chaparral (Hibbert, Davis, and Scholl 1974 and Brown, O'Connell, and Hibbert 1974), and phreatophyte and riparian (Horton and Campbell 1974).

The discrepancies between the University and Forest Service estimates of possible increases in water yield following manipulation of the vegetation cover are due to differing approaches. The University figures give the total amount that could be realized if all areas in a vegetation type were to be treated irrespective of the restraints needed because of other resource uses, such as wilderness areas or wildlife refuges. The Forest Service figures cite the possible yield increases after restricted areas are subtracted from the total type area.

Because the Phreatophyte Subcommittee was given the responsibility of the moist-site vegetation and not the forest and woodland zones, the report by Horton and Campbell (1974), will be discussed in detail and the others will not be covered until the responsibilities of the newly formed Vegetation Management Subcommittee are discussed.

Formation of the Phreatophyte Subcommittee

Along the river flood plains of New Mexico and Arizona very critical water shortages developed in the 1930's. About the same time, saltcedar (Tamarix chinensis Lour.) 1/ began aggressively spreading along these flood plains and obviously using large amounts of water. In New Mexico, concerned agencies formed such cooperative groups as the Salt Cedar Interagency Council, which on July 21, 1950, formed the Salt Cedar Interagency Task Force for New Mexico. These local groups (their names changed several times) conducted many public meetings and prepared extensive reports on the New Mexico situation and promoted action programs.

1/ The author agrees with Baum (1967) in rejecting the use of the name Tamarix pentandra (Pall.) for saltcedar.

Research studies and limited experimental eradication programs had been carried on in other states of the Southwest. Of particular merit was the elaborate research of the U.S. Geological Survey near Safford, Arizona. The need for wider coordination of these efforts became apparent and the problem was presented in full to the Pacific Southwest Federal Inter-Agency Technical Committee in March 1950. By December the Phreatophyte Subcommittee had been formed and members of the six participating agencies selected. The first official meeting of the group was held on January 16-17, 1951 (Case 1969).

The assignments given to the Subcommittee by its parent included briefly: (1) Accumulate information on all research and action programs in the phreatophyte field; (2) Coordinate these activities; (3) Sponsor additional research and action programs, often as cooperative efforts; and (4) Make available known information to all interested agencies and individuals.

McDonald (1961) listed in full the objectives and functions of the Phreatophyte Subcommittee.

Increased cooperation between interested agencies was brought about when the parent committee reorganized and became the Pacific Southwest Inter-Agency Committee in 1955. This new committee included the States of the Southwest; therefore, State representatives were appointed to the Phreatophyte Subcommittee.

Formation of the Vegetation Management Technical Subcommittee

For twenty years the Phreatophyte Subcommittee functioned successfully. During the first decade, activities concentrated on: (1) The water losses caused by phreatophytes; (2) The amounts of water that could be saved by clearing; and (3) Control methods aimed at complete elimination. More recently emphasis has shifted to the other possible values of these species and ways to develop compromise management systems, including recreation, wildlife, and other resources. Consequently, by 1970 it was felt that broadening the responsibilities of the subcommittee to include management of all wildland vegetation types would be desirable and would create more interest without any loss to the studies of phreatophytes. The functions of the subcommittee were thus increased, and the first meeting of the new Vegetation Management Technical Subcommittee was held on March 16, 1971. The objectives of the new subcommittee were outlined and approved at the 70-2 meeting of the Phreatophyte Subcommittee as follows:

"The primary objective of the Vegetation Management Technical Subcommittee is to stimulate programs related to water quantity and quality in managing vegetation in all life zones. The benefits and detriments from any program of management must consider all environmental resources affected. This would include but not be limited to effects on man, fish and wildlife, soil, recreation, wood fiber, and livestock.

"To serve as a source of information on vegetation management as related to water quantity and quality, and to disseminate that information to the parent committee, and

federal and state agencies. To maintain liaison and a working relationship with other groups and individuals concerned with vegetation management" (Phreatophyte Subcommittee 1970).

MEASUREMENT AND EVALUATION OF WATER LOSSES FROM MOIST-SITE VEGETATION

A primary objective of the Phreatophyte Subcommittee was to promote studies properly evaluating water losses from moist-site vegetation and to determine possibilities of water salvage by vegetation removal or manipulation. This need required research aimed not only at determining water losses from individual plants under different environmental conditions but also at evaluating stream-reach losses and the effect of vegetation removal (Horton and Campbell 1974).

Measurements of evapotranspiration losses from individual plants started many years ago, often using plants grown in containers. Most of these early studies were limited in scope. With time and experience, the containers became more refined and detailed, until very elaborate evapotranspirometers were built which measured changes in the environment as well as in the soil water. Many other methods also have been tried to determine actual transpiration losses from the individual plant or a cut shoot, such as the plastic evapotranspiration tent and the Scholander pressure chamber.

Tanks and Evapotranspirometers

The first major studies to determine water losses from specific moist-site wildland species were done with the use of metal cylindrical tanks varying from 2 to 10 feet in diameter, depending on the species to be studied. In all cases, these tanks were maintained with a specified water table varying from 2 to 6 feet below the soil surface. Unfortunately, plants grown in small tanks may respond very differently from mature plants in the field. They are subject to very different environmental conditions which affect the water-loss readings. In spite of these handicaps, tank data may be all that are available for many species under different climatic and water-table depth conditions.

The studies started by the California Division of Water Resources in 1927, using willow, cattails, and several species of grasses and rushes, showed that water losses from these riparian plants may equal or be greater than evaporation as measured from a Weather Bureau pan close by (Young and Blaney 1942). Use of water increased markedly as depth to the water table decreased. One of their studies demonstrated that tanks should not be isolated and thereby receive advected heat from the side (Taylor and Nickle 1933a). Tules (cattails) grown in an isolated tank lost about three times as much water as those in a tank placed in a dense cover of the same species.

Carlsbad, New Mexico

The Pecos River survey in 1939-40 included tanks that were planted to saltcedar, sacaton (Sporobolus airoides), and saltgrass (Distichlis stricta) at Carlsbad, New Mexico (Blaney and others 1942). This installation used small metal tanks large enough for only one saltcedar shrub and not well buffered from the influences of radiation and wind from the sides. There was no replication and the study was run for only one season, which did not allow sufficient time for development of the shrubs. The grass, however, grew vigorously under these conditions of shallow water and maximum light. It can be concluded that a comparison of water losses between saltcedar and grass based on these results is not valid.

Gila River, near Safford, Arizona

The flood plain of the upper Gila River, Graham County, Arizona, was studied first by Turner and Halpenny (1941) of the U.S. Geological Survey who established tanks near Safford, planted to saltcedar and seepwillow (Baccharis glutinosa).

A second and more extensive study of the upper Gila River by the same agency included a more detailed tank study established at Glenbar, Arizona (Gatewood and others 1950). These tanks had large single shrubs planted in duplicates at different water-table depths. The readings during the first year are very comparable to the Carlsbad readings. During the second year, however, growth was vigorous and the water losses high, probably much higher than typical saltcedar. Nevertheless, these figures have been widely used to estimate losses from flood-plain reaches. This has contributed to the many overestimates published of water losses from various rivers and the amount of water that could be salvaged by clearing.

Incorrect estimates of salvage potential have occurred also through faulty extrapolation techniques. The Glenbar study used a correction factor to adjust their data to water use at "100% volume-density" of foliage. This correction essentially adjusted water use by existing vegetation to a theoretical value based on the potential amount of vegetation for the given space. Though this concept has largely been dropped, in part due to the presentation at the Phreatophyte Subcommittee meeting in Alamosa, Colorado, in September 1963, a 9.2-foot water loss at Glenbar still appears in the literature (Robinson 1967).

Data questioning accuracy of 100 percent volume-density correction did not appear in publication until recently. Van Hylckama (1970) showed a nonsignificant 10-15 percent drop in evapotranspiration from stands of saltcedar thinned 50 percent as compared to dense stands in the tanks. In van Hylckama's own words, "...if a certain water use by a stand of 50 percent volume density is measured, a prediction as to what might happen when this stand develops to 100 percent volume density will lead to conclusions that may be grossly overestimated." And to quote from part of van Hylckama's abstract, "...the claims as to the quantity of water potentially saved by their (saltcedar) eradication could well be overestimated."

It must be borne in mind, however, that the errors using this method may be in the other direction. For instance, if a stand of 80 percent volume density uses 7 feet of water, a stand of 40 percent volume density would be determined to utilize only 3.5 feet. But van Hylckama's 1970 figures show that if vegetation in an 80 percent stand is reduced by 50 percent, water use would actually drop only 10 to 15 percent instead of the 50 percent indicated by the 100 percent volume-density approach. In other words, an actual reduction to about 6.2 feet instead of 3.5 feet of annual water loss. Thus, estimates of water loss would be too low for areas with computed volume density lower than the standard used at Glenbar.

Buckeye, Arizona

Due to the relatively small size and known inaccuracies of the metal tanks, large plastic-lined evapotranspirometers were designed and built to study water losses from phreatophytes. A block of soil was excavated in alluvium measuring about 1,000 square feet in surface area and 8 to 15 feet deep. The hole was lined with heavy plastic. Various types of instruments were added to measure the water depth, to determine environmental conditions, and to allow pumping and draining of contained water if desired. After these controls were installed, the tank was filled with the excavated soil.

The large area of the research installation and the ability to completely buffer the study plants to a large extent removed the problem of isolation. The elaborate method of adding water to the water table to compensate for evapotranspiration allowed accurate operation and data collection without disturbance of the plant cover. The greater depth of soil and the longer study period produced a more mature cover and a more representative simulation of natural conditions. The greatest difficulty encountered was the accumulation of salt in the water table which, unexpectedly, greatly affected growth and water losses.

The first such installation was a set of six tanks built in 1959 for saltcedar studies at Buckeye, Arizona, by the U.S. Geological Survey in cooperation with the Bureau of Reclamation (van Hylckama 1974). By the third growing season, the cover was nearly mature and beginning to reach the pattern of vigorous spring growth and a more or less dormant summer period with reduced evapotranspiration. The readings in the Buckeye tanks show a very definite relationship of moisture loss to water-table depth. Saline conditions in the ground water were concluded to have reduced the evapotranspiration losses very markedly. Water use of tanks thinned to 50 percent of original cover was reduced only 10 to 15 percent; cutting shrubs back to 18 inches in height reduced water use by 35 percent.

Bernardo, New Mexico

Another set of large plastic-lined tanks was built in 1961 by the Bureau of Reclamation near Bernardo, New Mexico (U.S. Bureau of Reclamation 1973a and 1973b). These evapotranspirometers were similar to the Buckeye ones except they were designed to be readily flushed when necessary to reduce salt accumulations in the ground water.

The Bernardo tanks show a different relationship between water loss and water-table depth, which appears to contradict some of the other tank studies. When the root systems were developed, the water loss from the deeper water tables were sometimes close to losses from the shallower depths, if the ground water was reasonably free of salt. It is interesting to speculate on the reason. Perhaps it is biological. Could the shrubs extract water equally well throughout the summer from the deeper depths at the cooler temperatures at Bernardo, while the intense desert summer temperatures at Buckeye would reduce water movement more from the deeper depths than from the shallower? In confirmation, we know that the evapotranspiration at Buckeye was reduced in the summer.

Another interesting result of the Bernardo study was the reaction of the plants to a water-table change from a 5.6-foot depth down to 9 feet. When the water table was dropped rapidly by pumping, the amount of water loss was almost cut in half. In the next year, however, the root system apparently recovered and even at the 9-foot depth it was using nearly as much water as it had at the shallower depth. The tank in which the water table was lowered by plant water use showed a less dramatic reaction.

The Bernardo tanks also demonstrate that a 3-foot water-table depth is too shallow for optimum growth of saltcedar.

Some tanks were planted to saltgrass with water-table depths at 2.5 feet or less. Present results are somewhat confusing because of differing methods of grass establishment and varying water-table depths. Studies have been started to determine more accurately water losses from saltgrass.

Additional studies with several species and including the effect of antitranspirants are continuing at the Bernardo installation.

Other Tank Studies

There were two other U.S. Geological Survey installations--one at Yuma, Arizona, which studied arrowweed (Pluchea sericea), saltbush (Atriplex sp.), and Bermudagrass (Cynodon dactylon) (McDonald and Hughes 1968) and one near Winnemucca in northern Nevada which used Great Basin wetland species (Robinson 1970). Both of these studies are now terminated.

Conclusions: Based on the tank data, a mature, dense, unbroken stand of saltcedar growing in the higher elevations of Bernardo, New Mexico, would utilize 4 to 4.5 feet of water per year, if growing on a site with a shallow water table. At the elevation of Safford, Arizona, the figure is probably in the neighborhood of 5 to 6 feet per year. The water loss from saltcedar at Carlsbad, New Mexico, would probably be about the same or slightly less. In the Buckeye area, dense saltcedar would utilize 6 to 7 feet of water per year. Water use would be reduced by excessive salt in the soil or ground water in any of these locations.

Arrowweed at Yuma used very high amounts of water (8 feet) but saltbush water use was surprisingly low (3 to 4 feet) at the same water-table depth. Bermudagrass used 6 feet at somewhat shallower depth.

These figures are not conclusive, of course, but they are reasonably consistent. It should be stressed again that these losses are for dense, mature vegetation which usually occupies a relatively small proportion of a flood-plain area; where vegetation is more open, the water losses can be greatly reduced.

However, these tank data, in spite of their weaknesses and perhaps inaccuracies, are the most detailed that are available on water losses from saltcedar and certain associated species. Other methods which are not as expensive to construct or maintain are definitely needed to obtain detailed relations of water losses from individual shrubs of various species to environmental conditions. But it must be borne in mind that carefully designed instrumentation may produce better and faster results at less cost in the long run than initially cheaper and less accurate types of research efforts.

Application of Moisture-Loss Data to Flood Plains

Tank studies were primarily established to estimate water losses from flood plains and to justify phreatophyte clearing (National Resources Committee 1938, National Resources Planning Board 1942, Gatewood and others 1950). It was hoped that water losses could better be predicted for any area if positive information on water losses from the vegetation were known. For many years, attempts have been made to predict moisture losses solely from environmental factors. These approaches utilize a basic formula which states the relationship of evaporation of water to energy from the sun. Some of these formula approaches are very simple and include only temperature and day length. Later formulas use additional factors such as humidity, wind movement, radiation, and vegetation response (Criddle 1966, Jensen 1966, Cruff and Thompson 1967).

Probably the most widely used approach, especially in river-basin studies in the West, is the Blaney-Criddle formula (Blaney 1952a, Blaney 1952b, and Blaney and Criddle 1962). Essentially it is similar to other formulas (Thornthwaite and Mather 1957, Penman 1963) but requires a crop or vegetation factor (K) as well as information on temperature and day length. As originally prepared by Blaney and Morin (1942), humidity was also used but this factor was dropped in the more recent applications. The energy factor is computed from temperature and day length. The vegetation factor (K) varies with the species, percentage of cover, and season; to a large extent it is based upon data from tank studies. The Blaney-Criddle method has many of the weaknesses of the other empirical formulas but it is simpler, and if vegetation data are available, predictions are closer to the actual water loss than by any other formula. Rantz (1969) while improving the applicability of this formula to phreatophyte areas, used K factors derived from tank data which, therefore, may be too high. He suggests that these figures be used only where other quantitative data are not available. Hanson, Kipple, and Culler (1972) as part of their studies of the Gila River flood plain applied the Blaney-Criddle equation to the

water-budget evapotranspiration values to provide a basis for extrapolating the data to other areas of similar phreatophyte cover. Horton, Robinson, and McDonald (1964) developed a method of surveying vegetation density to use as a factor in estimating water losses.

Conclusion: These promising methods of estimating water losses from phreatophyte areas are now limited by inadequacies of quantitative data to apply in the computations.

Evapotranspiration Tent

With the desire to measure transpiration directly from phreatophyte plant parts or individual shrubs, the evapotranspiration tent was developed by the USDA Forest Service at Tempe, Arizona. It was first used as a laboratory procedure for measuring the transpiration of potted plants under controlled light, humidity, and temperature (Decker and Wetzel 1957).

A field apparatus was developed with a frameless cylindrical 10- by 10-foot tent made of transparent plastic film. This film was thrown over the plant and inflated by ventilating blowers. The humidity of the airstream entering and leaving the tent was measured with a hygrometer. Field observations were made along the Salt River near Granite Reef Dam, Arizona, on transpiration rates of isolated shrubs of tamarisk surrounded by Bermudagrass sod. Evapotranspiration of tamarisk-Bermudagrass stands increased linearily with the amount of tamarisk, with the larger shrubs using two to three times as much water as Bermudagrass sod (Decker, Gaylor, and Cole 1962).

The artificial microclimate formed by the enclosed evapotranspiration tent became apparent in a study on the Gila River west of Safford, Arizona; mesquite (Prosopis juliflora) and tamarisk shrubs growing with deep water tables were defoliated after 8 hours inside the evapotranspiration tent. This indicated a very serious enclosure effect which had not been apparent in the Salt River studies where high water tables and, therefore, sufficient surplus water kept the plants alive. Mace (1968) redesigned the evapotranspiration tent to increase the amount of ventilation because he determined that the serious enclosure effect was due in part to poor ventilation inside the tent, rather than entirely to the greenhouse effect of the plastic. However, there is still a serious question about the use of the evapotranspiration tent and its effectiveness in determining rates of water loss in the field. The enclosure effect was discussed by Lee (1966) and again by Mace and Thompson (1969).

Sebenik and Thames (1967) used the tent modified by Mace to measure evapotranspiration from tamarisk on the San Pedro River, Arizona. Their water-loss figures are among the highest published, probably due in large part to the enclosure effect.

Conclusion: The evapotranspiration tent is not now recommended as a result of these studies critically evaluating enclosure effects.

Heat-Pulse Meter

Swanson (1962) helped develop instrumentation for detecting the movement of sap in the stems of conifers. A correlating run with the evapotranspiration tent (Skau and Swanson 1963, Decker and Skau 1964, and Swanson and Lee 1966) indicated sap flow might possibly be used to measure the rate of transpiration. One difficulty is the determination of the amount of moisture moving upwards in the stream of water because the instrument records only the rate of movement, not the amount which is flowing. However, Swanson (1972) reported a definite correlation of transpiration to heat-pulse velocity in young Aleppo pine during clear summer days at Tempe, Arizona. The heat-pulse meter is better adapted for use in conifers than in hardwood species because of the greater homogeneity of wood of conifers. Tests by the Forest Service indicate that sap velocity in mesquite is highly variable from hour-to-hour and appears to lag actual transpiration well into the night.

Daum (1967) developed another type of instrumentation to measure water transport in tree trunks using heat-flow analysis. In the preliminary experiment, a mature ash, a hardwood tree, was used with apparent success.

Conclusions: Because of these environmental influences and inherent variability of sap flow it can be concluded that in mesquite, and perhaps in all hardwoods, techniques of integrating a number of sap-velocity measurements in the cross section of a trunk are too crude to warrant interpretations of transpiration rates.

Pressure Chamber

Considerable work has been reported in recent years on techniques for determining moisture stress in plants. The use of the pressure-bomb technique in watershed management research has been evaluated by the Forest Service (Horton and Campbell 1974). The pressure bomb (Scholander and others 1964 and 1965; Boyer 1967; and Kaufman 1968) appears to be an effective field and laboratory method for determining an index of leaf-water potential and internal water stress of some plants. The technique consists of placing a leafy shoot, or single leaf, inside a steel chamber with the cut end exposed to the atmosphere. Pressure of dry nitrogen is increased within the chamber until xylem sap begins to bubble out from the cut end at which time the pressure is recorded. This technique is particularly suited to field conditions because of rapidity of measurements, and low cost and dependability of equipment (Waring and Cleary 1967). Because the pressure needed to force water from leaf cells to the cut xylem surface is basically a function of leaf-water potential, predawn pressure-bomb readings can be considered an index to soil-moisture availability within the root zone.

Conclusions: In spite of some encountered difficulties, the pressure-bomb technique to determine water requirements appears to be a useful tool in watershed management. While this instrument does not give the amount of water being lost, it can readily segregate

those plants which have water available to them and which are obtaining their water from the deeper water supplies even during a period of drought. Thus, those phreatophyte areas that are utilizing ground water can readily be determined by use of this technique (Campbell 1973).

Phreatophyte Flood-Plain Reaches

Research in phreatophyte water losses was always aimed at determining the effect of vegetation clearing upon water yield. Data from tanks planted to phreatophyte species have been widely used for this purpose. Unfortunately, the amount of possible water salvage has sometimes been exaggerated by using the maximum figures of water loss from tanks. Gatewood and others (1950), averaging six different methods, estimated that total use of water along a section of the Gila River in Graham County, Arizona, during the study in 1943 and 1944 was 28,350 acre-feet (including precipitation) of water from 9,303 acres of bottom-land vegetation. This amounts to a total water loss of about 3 acre-feet per acre of phreatophytes. Data derived from the tank study (one of the six methods used) indicated that the total water loss was approximately 18.7 percent higher than the average of the six methods. Inasmuch as saltcedar was the principal vegetation, the high water-loss figures obtained from the saltcedar tanks could explain the higher estimate of water loss by this method. The authors state that a large percentage of the water loss could be saved by clearing the phreatophytes, but they made no estimate of the actual amounts.

Turner and Skibitzke (1952) estimated that the clearing of a 2,000-foot channel along the Salt and Gila Rivers in Arizona would save somewhat less than 1 acre-foot per acre.

In contrast, Blaney and others (1942) concluded from the short-lived tank study at Carlsbad that saltcedar along the riverbeds would use 6 feet of water per year and, away from the river, about 5 feet. This figure was used in the hearing on the proposed phreatophyte control along the Pecos River. Testimony was given that phreatophytes, principally tamarisk, would consume 5 to 6 acre-feet of water, and about half of this water could be saved by clearing (U.S. Senate 1963).

Unfortunately, there are few actual figures of water savings obtained by phreatophyte clearing. The most complete is a recent study that the U.S. Geological Survey conducted along the Gila River west of Safford, Arizona. About 45 percent of the study reach to be cleared was under dense phreatophyte cover of saltcedar and mesquite, with the remainder open vegetation. The average consumptive use was 50 inches per year before clearing and only 20 inches after clearing; this would mean a reduction of water loss of 30 inches or 2.5 feet over the cleared area (Hanson, Kipple, and Culler 1972). Replacement vegetation would reduce this water salvage (Culler 1970).

Riparian Reaches

Some estimates of evapotranspiration have been obtained from riparian reaches and these data are not necessarily transferable to other sectors. Plant-species diversity

(frequency, composition, and age) and highly variable environments create a situation where no completely satisfactory method has been developed. In certain areas, stream-gaging stations have been used above and below stream reaches. A soil-water budget analysis can then be used to estimate evapotranspiration by total inflow minus outflow, corrected by such factors as deep drainage and soil-moisture storage.

Thomsen and Schumann (1968) used the water-budget analysis method to study water resources of Sycamore Creek, Maricopa County, Arizona. In a 5-year period, water-budget analysis indicated that water loss from the channel on the lower 10 miles of Sycamore Creek averaged 1,500 acre-feet. In the channel and flood plain, riparian vegetation covered about 1,400 acres. Thus average evapotranspiration loss from the 10-mile reach was estimated to be only 1.1 acre-feet per acre.

Bowie and Kam (1968) used soil-water budget analysis and transpiration-well data on Cottonwood Wash in northwestern Arizona to indicate effects of removing riparian vegetation from a 1.5-mile section of stream channel averaging 130 feet wide and totaling about 22 acres. The average amount of water saved after removing the cottonwood (Populus fremontii) and some willow (Salix sp.) and seepwillow (Baccharis glutinosa) from this reach was estimated at 1.7 acre-feet per acre or a savings of 6 percent of inflow. Even though this cottonwood stand is quite typical of a Southwestern stream at this elevation, the application of these data to other areas must be done with caution. Tree-crown canopy was reported as covering only 5.9 acres or 26.8 percent of the reach area of 22 acres. Thus water salvage would be 6.3 acre-feet per acre of actual tree crown. This illustrates the difficulties of relating vegetation density to water losses. In this case, the isolated individual trees or groups of trees would receive far more direct energy from the sun than trees in a continuous canopy and would, therefore, transpire more water.

Regrowth of shrub-type vegetation, such as seepwillow, soon reduced the water savings effected by the removal of tree-type vegetation. Water quality did not change significantly downstream following treatment.

Watershed studies in riparian zones in the San Gabriel Mountains of southern California exemplify both a successful application of water-budget analysis and the effect of vegetation treatment (Rowe 1963). Thirty-eight acres of woodland-riparian vegetation was removed along the lower reaches of Monroe Canyon; of this, only about 3.8 acres were riparian species with the rest composed of woodland species common to adjacent canyon slopes. Following treatment, the flow from Monroe was increased 17.4 acre-feet or about 0.5 acre-feet per acre treated. It is probable, however, that the riparian areas had a much greater increase than this. Chemical analysis revealed no changes in chemical content or total solids due to treatment. Removal of canyon-bottom vegetation and the resultant insolation of the stream channel did result in an appreciable higher concentration of green algae, especially in summer flow.

Conclusions: These riparian reach studies indicated rather consistent increased water yields were obtained following riparian treatments. Somewhere between 1 and 2 acre-feet

of water per acre cleared is a good approximation of probable savings. These water yields would have to be weighed against losses or gains from other resources such as wildlife habitat and food, fish habitat, grazing, recreation, and esthetics for evaluation of possible benefits (Campbell 1970).

Use of Energy Measurements

Energy measurements have often been used to determine evapotranspiration losses and it has been found possible with the use of sophisticated and expensive instruments to accurately predict the amount of evapotranspiration losses from homogenous vegetation surfaces. The different methods and approaches are thoroughly discussed in Conference Proceedings of both the American Society of Civil Engineers (1966) and the American Society of Agricultural Engineers (1966).

Unfortunately, comparatively little work has been done in forest or other irregular or discontinuous types of cover. In phreatophyte areas, research is needed to determine the so-called "oasis effect"–the advective energy relationships between the transpiring area and the surrounding desert or semi-arid climate. These irregularities of energy input and output are extremely difficult to evaluate (Abdel-Aziz, Taylor, and Ashcroft 1964). No present research studies these phenomena in relation to phreatophyte cover, but the results of the studies on agricultural cropland would indicate that there should be possibilities of determining evaporation losses from larger areas of phreatophyte vegetation. Likewise, there are possibilities of developing methods such as remote sensing or laser beams to measure moisture content of the air surrounding the phreatophyte zone. Color-infrared photographs were successfully correlated to water-budget measurements as part of the USGS Gila River Phreatophyte Project (Jones 1973).

Conclusions: Research should be pushed aggressively in search of new applications of these or other techniques in relation to water losses from woody vegetation.

PHREATOPHYTE AND RIPARIAN COMMUNITIES

To properly manage phreatophyte and riparian vegetation, a knowledge of the present community relationships is required as well as an understanding of the individual reactions of the component species to environmental conditions. Drastic changes in land use and water regime caused by man's activities have brought about striking results on many of the vegetation communities, particularly flood-plain areas (Turner 1974).

The extensive ecological studies on forest, woodland, and chaparral species are not included as these zones have not been considered in the sphere of the Subcommittee in the past.

Phreatophyte Flood Plains

The original vegetation of the flood-plain areas was determined primarily by the water supply available to plant roots. Undoubtedly, the rivers flowed rather constantly and the

water tables were high in much of the valley area. The area close to the river was usually dominated by a wide band of trees, principally cottonwood, with such associated species as willows. On the higher ground were large mesquite bosques. Arrowweed was probably dominant in many areas. In the more saline areas there were large patches of salt-tolerant grasses, surrounded by saltbushes and other salt-tolerant plants.

The early pioneers used the cottonwood, mesquite, and other trees and larger shrubs for fuel and for building their homes. In the Arizona desert, the lands dominated by mesquite were some of the best soils in the valley and were soon cleared for farming. Along the Rio Grande, the first and finest farmland was created by removal of cottonwood.

The Old World tamarisk, or saltcedar, found conditions ideal for rapid invasion of the flood-plain areas. The abundantly produced seed will germinate very rapidly on warm, moist soil but several weeks are needed for the seedlings to produce enough roots for survival (Horton, Mounts, and Kraft 1960). Thus, this species thrives best in an open situation such as along moist sandbars or areas disturbed by floodflows and, when conditions are ideal, invasion will be rapid.

All of the above-ground portions of saltcedar will develop adventitious roots and form new shrubs if kept wet in moist soil. Gary and Horton (1965) found that 100 percent of stem cuttings would sprout at all times of the year if they are kept moist and warm. Root cuttings did not sprout. Saltcedar shrubs will resprout vigorously after burning or cutting; likewise they can withstand very heavy grazing (Gary 1960, Campbell 1966).

The native phreatophyte species likewise possess characteristics enabling them to spread rapidly where conditions are favorable for their growth (Horton and Campbell 1974) but tamarisk is more aggressive. The mature shrubs are more drought resistant than the native species. Thus saltcedar can readily replace the native species under many present flood-plain conditions.

First introduced into the United States as an ornamental shrub, tamarisk was sold at nurseries in the East as early as 1823 (Horton 1964). By 1856 it was being sold in California nurseries. In 1901 it was recorded as a naturalized shrub along the Salt River at Tempe, Arizona. Thornber (1916) stressed the desirability of using Tamarix of several different species around buildings for landscaping, hedgerows, and shade, as well as other types of plantings in the desert areas.

Saltcedar was beginning to spread along the flood plains of the major rivers in the 1920's (Robinson 1965). By the 1940's, extensive areas dominated by saltcedar were prevalent along the Gila (Marks 1950, Haase 1972, Turner 1974), Salt (Turner and Skibitzke 1952 and Gary 1965), Rio Grande (Campbell and Dick-Peddie 1964) as well as along the Pecos and Colorado. It is now also found along many smaller streams, around springs, by roadsides, and in many other areas of the West wherever there is sufficient moisture to germinate the seeds and establish the seedlings.

Closeup of saltcedar. Densely growing shrubs of saltcedar (flood-plain Zone 3) near Buckeye, Arizona. (U.S. Geological Survey Photograph No. W58-155)

Along some flood-plain reaches, dropping water tables have reduced the stand of saltcedar, because ground water is now apparently out of reach of its roots. In the 1940's, a dense stand of saltcedar extended along the Salt River from east of Mesa through Tempe and Phoenix to the junction with the Gila. Shrubs are now growing along this river only as widely spaced desert-type plants dependent on floodflows and rain for survival. Fires burning through these areas kill a fairly large number of plants and create an even more open stand. It is probable, in this desert climate, that shrubs must be spaced 15 or 20 feet or more apart to be able to have sufficient root systems to withstand lengthy droughts. A heavy, dense stand will survive only where the water table is within 15 or 20 feet of the surface.

Conclusions: Saltcedar has aggressively spread over a very large portion of the western flood plains but has probably reached its maximum spread in most of the area. However, it will always threaten to aggressively invade after any change in local conditions. Thus its ecology must be understood if management of flood-plain vegetation is to be successful.

Other Moist-Site Communities

Man's impact on moist-site vegetation types now dominated by mesquite, cottonwood, sycamore, or alder has not been as great as on the major flood plains. Ecological characteristics of these types and their component species have been discussed by Horton and Campbell (1974). Management approaches will be considered later in this paper. An extensive bibliography, well annotated, has been prepared for mesquite by Schuster (1969).

OTHER RESOURCE USES OF MOIST-SITE AREAS

The emphasis on use and management of moist-site areas has recently changed from water salvage to the possible development of other alternatives (Horton 1972). It should be borne in mind that water is still of top priority and should always be considered in management plans for moist-site areas. However, determination of what would be the best use of water which could be salvaged by treatment of a particular site requires: first, careful evaluation of resources favored by the existing cover; and second, determination of the effect of manipulation of vegetation upon present resources and the creation of new values, including the additional water. Some resource uses, such as the removal of shrubs and trees to develop farmlands or to use these areas for grazing, are relatively easy to justify and to determine the economic values involved. Other more intangible resources, such as recreation, wildlife, preservation of natural areas, etc., are difficult to evaluate. Determining the most desirable alternative is sometimes controversial because the resources involved are backed by a single user who feels that his resource overshadows all others.

Water rights must be considered first in all land management plans. In many areas such as New Mexico and the Arkansas River in Colorado, additional water rights for increased water use are not created by clearing phreatophytes. Any such salvaged water

on fully appropriated streams must go back to the stream system for use by the appropriate water-right holder. Arizona law is more flexible. For example, at the present time, the landowner owns the right to use the ground water underlying his property but his use and development of this water is restricted, especially in critical ground water areas. Though he may not be allowed to drill new wells, he can pump existing wells harder or he can deepen them or he can abandon them and drill bigger and deeper wells to replace them if the water is used beneficially on his own land (Kelso, Martin, and Mack 1973). Thus, multiple-use management must consider the above legal aspects for a particular site before evaluating possible further resource development.

Moist-site areas extend through many urban communities. These provide excellent opportunities for careful development of park and other recreational facilities. Flood control in some sites has been designed to allow full public use of these areas. Because this report is essentially wildland management, no further details of these possibilities are outlined.

Development of Farms and Grazing Lands

Along most of the flood plains, clearing of phreatophyte cover for farm or grazing land has caused the greatest attrition. In many cases, the soils are admirably suited for these purposes even though they can be subject to flooding. This flooding may be alleviated by construction of dams upstream, which allows the farm activity to extend close to the channel. Alkalinity of much of the flood plain now covered by phreatophytes may be too high for farming, however. Where water is fairly close to the surface or can be obtained, grazing is often a desirable use for such lands if woody vegetation is removed.

Wildlife

Phreatophyte areas can provide shelter for many species. Of topmost interest are white-winged and mourning doves. The white-winged dove nests in large numbers in phreatophyte areas in Arizona, and is a valuable hunting resource (Cottam and Trefethan 1968). Historically, doves nested in mesquite bosques which produced much more food than the extensive saltcedar thickets of today (Arnold 1943). Clearing of the mesquite depleted the dove numbers, which were not restored until saltcedar invaded the area. Dense woody stands of saltcedar provide nesting sites, but the food--as for most wildlife--must be provided in large part from areas outside the flood plains. Large numbers of doves feed primarily on agricultural fields nearby. When these depredations become severe, the farmer, especially in the Gila River Valley around Buckeye, often changes his type of crop. To maintain an optimum population of these doves, it may be necessary to devise special means to provide food for them.

Game departments have long been interested in using phreatophyte areas as wintering grounds for waterfowl, particularly on the Rio Grande and to some extent on the Pecos River as well as the Gila River in the Buckeye area (Fleming 1959). The Game and Fish

Departments in both Arizona and New Mexico cleared areas for the production of green forage. A compromise must be made between preserving cover for nesting of doves and removal of cover to produce food for waterfowl and possibly for doves. These clearings should be arranged to give maximum water salvage and to provide passage for floodflows.

Recently the value of cottonwood and other phreatophytes for nongame birds has been stressed. The highest concentration of birds noted anywhere in the United States has been reported by Johnson (1970) from the cottonwoods of the Verde Valley in central Arizona. The most birds and greatest diversity of species occur in areas containing the densest riparian vegetation. Results of the study indicated that thining cottonwood for water savings and flood control reduced nesting bird populations.

This form of wildlife use has intangible values which are very hard to evaluate. Rare or endangered bird species must be evaluated in any management plan, particularly in the cottonwood stands of southern Arizona close to the Mexican border.

Development and maintenance of a fish population is the major use of most mountain streams.

Recreation

Heavy saltcedar stands are not particularly valuable for recreational purposes; campgrounds are not appropriate mainly because of the summer heat and because of the unpleasant exudation of salt from the saltcedar cover, especially on warm mornings. The shrubs are bare during the fall and winter and they are attractive only for a relatively short period in spring when many are in full bloom. Saltcedar areas could, of course, be converted to other phreatophyte types; for instance, they could be cleared and cottonwood or mesquite established.

The development of picnic and camping areas is a most important recreation use in cottonwood areas and near mountain streams. Cottonwoods are appealing and are definitely needed in areas close to roads or where recreation facilities can be established.

Preservation of Natural Conditions

Due to the changes in phreatophyte areas throughout the Southwest, the preservation of natural conditions is rarely a factor. There are areas in southern Arizona and southern New Mexico, however, where canyons have retained their natural ecological balance. The desirability of preserving these areas is very great.

Flood Control and Erosion Prevention

Vegetation growing on a river flood plain has a major effect on the characteristics of a major flood. This has been studied in great detail by the Gila River Phreatophyte Project of the U.S. Geological Survey (Burkham 1972) 1/.

1/ Two other USGS Professional Papers by D.E. Burkham are in press:
655-J. Hydraulic effects of changes in bottom-land vegetation on three major floods, Gila River in southeastern Arizona; 655-K. Effects of changes in an alluvial channel on the timing, magnitude, and transformation of flood waves.

Saltcedar and other species tend to clog a channel because the seedlings invade sandbanks and sandbars close to the stream. As they develop a barrier, sediment collects in the heavy stands. Floodflows are then diverted onto the surrounding lands. This spreads the woody barriers more widely, which further increases the flooding potential. Major floods then open a new channel through this accumulated dense cover.

Deposition of debris above the delta of a reservoir may be beneficial if it keeps the sediments from entering the reservoir and reducing its storage capacity. Another factor that must be kept in mind, especially after clearing, is the possibility of channel cutting after the banks are cleared of vegetation. Wind erosion likewise can be very serious after clearing.

Additional Resource Values

Other values of the moist-site species include the use of saltcedar stands as a refuge for bees, especially during the season insecticides are being applied to the croplands. Management of saltcedar for honey production needs more research. Colonies apparently must be widely spaced because of the possibility of disease. Spreading the colonies would allow for intervening areas to be managed for other purposes. Mesquite also is valuable for apiaries.

Tannin has been listed as a possible resource from saltcedar but the recent tests would show that these values are comparatively limited and it would not be possible to maintain any industry using tannin obtained from saltcedar.

Production of fuel wood is not important from most saltcedar areas but it is very much so from mesquite bosques and the cottonwood areas. Of the numerous streamside species, only cottonwood and mesquite occur in extensive enough stands to support a timber utilization industry. Cottonwood has been used for pulpwood, wood shavings, crating, boxes, and pallets. In northern Mexico, a small industry presently utilizes cottonwood for wooden bowls and small statues. In Arizona, cottonwood is estimated to occur on less than 8,000 acres with the major concentrations in the Verde, Little Colorado, and Gila River drainages with present stands too scattered for most commercial concerns (Barger and Ffolliott 1971).

Conclusions: The interrelating of these resources to one another and to water salvage will require more understanding and research in order to be successful. Cooperation among all agencies is critical.

CONTROL METHODS

To establish optimum multiple-use management in most phreatophyte areas, some control or manipulation of portions of the vegetation will usually be required. This activity, of course, should be carried on only after all desirable restraints are studied and possible consequences considered.

Mechanical

The early clearing projects in saltcedar areas were done with a bulldozer; the shrubs were bulldozed into piles and burned when dry. This badly disturbed the soil surface and was expensive. Often many small roots, root crowns, and broken stems left in the soil sprouted and formed a new cover. Thus many earlier clearings were not too successful.

At present, the root plow seems one of the most successful mechanical methods. This root plow undercuts the plants and raises them so they dry out rapidly and are killed. Plowing can be done most effectively when the soil is relatively dry (Horton 1960). Large areas have been root plowed and then usually raked to get the material into windrows so it will not interfere with floodflows. Because root plowing tends to kill a large percentage of the grass cover mixed with the saltcedar, it may lead to serious wind erosion. Other mechanical methods of removing the brush were described by Lowry (1966).

Where grass is a factor in the understory, a rotary-type mower can cut the shrubs several inches above the ground. This does not kill saltcedar, but grazing can further reduce or control cover. Although larger plants cannot be cut in this fashion, the method is appropriate if the water table is close to the surface and heavy grazing can be applied.

Chemical

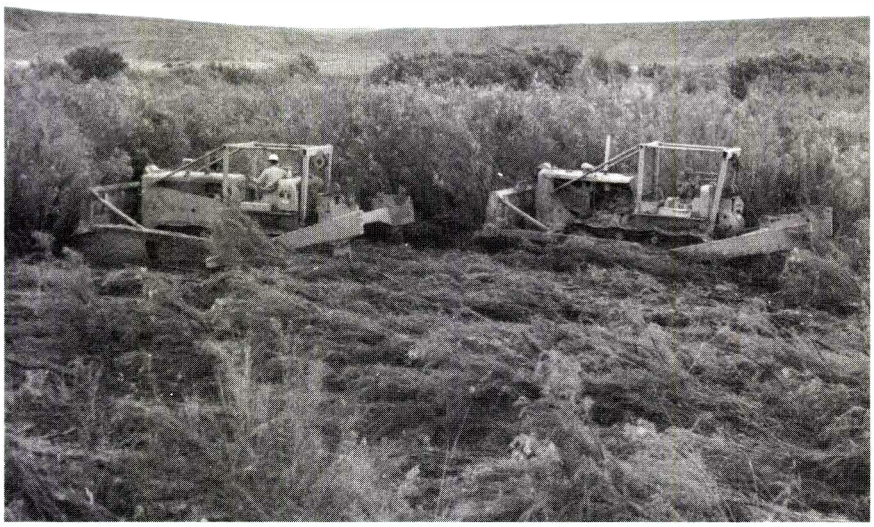
Chemicals have offered a relatively inexpensive method of vegetation control. Consequently, they have been widely used. It soon became recognized that they presented a serious threat to the environment and even to humans. As a result, there was an overreaction on the part of many people and groups and widespread restraints have been applied to their use. However, in spite of their present ill repute, careful research may indicate additional ways that chemicals can be used safely in vegetation control. Care will always have to be taken to use only those methods and chemicals that will not spread toxic particles to crops by wind movement. Also, water supplies in ditches, streams, and ground water must be protected. But, above all, danger to humans must be prevented.

Though much research had been done on the chemical control of saltcedar (Hughes 1966), no really satisfactory method has been developed. Translocation is relatively slow, and the sprouting ability of the root crown is such that there is not a good or consistent response to chemical methods.

The recent studies by the Agricultural Research Service at Los Lunas, New Mexico, indicate that the Chem-Plow would be successful in the control of saltcedar in many situations (Quimby 1971).

Antitranspirants

A great deal has been done with the use of chemicals to close the stomata and, therefore, decrease transpiration and water loss. Most studies with agricultural crops have also shown a corresponding decrease in the growth of the plant due to decreased



Flood-plain clearing, Pecos River Basin Project, New Mexico. Crawler tractors with root plow attachments undercutting saltcedar in Pecos River flood plain near Roswell, New Mexico. The root plow is designed to cut below the plant crown and the sloping blade being pulled through the soil will bring the crown and most of the roots to the ground surface. Root plows are used primarily for initial clearing and not for operation and maintenance. (USBR Photograph No. P1166-532-12NA)

Maintenance of flood plains and reservoirs, Pecos River Basin Project, New Mexico. View of Marden brush cutters being pulled by crawler tractors in Pecos River flood plain near Roswell, New Mexico. The rills left by the cutter blades are ideal for revegetation seeding; however, root crowns split by the cutters and heavy saltcedar stems may continue to grow. (USBR Photograph No. P1166-500-2NA)

photosynthesis. Davenport, Hagan, and Martin (1969) summarized research on antitranspirants and indicated that they might have application in increasing the yield of water from watersheds by reducing transpiration losses from vegetation. Such a reaction would be desirable in the treatment of phreatophytes, particularly where maintenance of a vegetation cover is desired. Brooks and Thorud (1971) evaluated various antitranspirants on saltcedar and indicated the method has possibilities. An extensive cooperative research program on the use of such chemicals on saltcedar is being carried out under the sponsorship of the Bureau of Reclamation and several universities. Davenport and others (1975) report reduction of transpiration was brought about by helicopter spraying a stand of saltcedar with antitranspirants in California.

Conclusion: Research in all promising types of mechanical and chemical control, including the use of antitranspirants, is needed to develop an effective method of vegetation manipulation to apply when a desirable management practice is determined for a given environment.

COOPERATIVE PHREATOPHYTE PROJECTS

The objective of the Phreatophyte Subcommittee included the sponsorship of many cooperative projects which combined the efforts of two or more agencies. Such projects included the gathering of available information on a specific study or problem for publication or the initiation of a research project. The following listing does not necessarily include all such projects but gives a good sample of the possibilities of such an approach.

Four symposia on phreatophyte problems have been held (1952, 1957, 1961, and 1966). In every case, the status of activities, summary of research to date, and plans for the future were fully discussed. Copies of the proceedings of the 1966 symposium are still available for distribution.

The status of phreatophyte knowledge was summarized by Robinson (1958) of the U.S. Geological Survey with the help of other subcommittee members. Likewise, Robinson (1959, 1964) compiled descriptions of all research projects in the western states that were being carried on by various agencies.

In 1956, a task force was set up to develop and standardize methods of surveying phreatophyte vegetation to use as a basis for estimating water losses. Provisional reports were issued by the Subcommittee and the final publication was released in 1964 sponsored by the Forest Service, Geological Survey, and the Bureau of Reclamation (Horton, Robinson, and McDonald 1964).

A compilation of all phreatophyte treatments either in progress or planned in the State of Arizona was requested by the Subcommittee. The Salt River Project, Arizona State Land Department, and Rocky Mountain Station (U.S. Forest Service) summarized and published the replies received from all action agencies in Arizona (Phreatophyte Subcommittee 1969).

Maintenance of flood plains and reservoirs, Pecos River Basin Project, New Mexico. Large size, rubber tire 1,000 gallon capacity spray tank with 75-foot spray boom operating in the Pecos River flood plain near Roswell, New Mexico. Systemic herbicides are used to control the growth of undesirable plant species yet allowing the desirable grasses to grow with minimal disturbance of the soil. (USBR Photograph No. P1166-532-57NA)

Maintenance of flood plains and reservoirs, Pecos River Basin Project, New Mexico. Closeup of heavy duty 84-inch diameter rotary mower used for operation and maintenance on the Pecos River flood plain near Roswell, New Mexico. The rotary mower which is driven from the tractor power takeoff is effective in cutting the top growth of plants up to 2 or 3 inches in diameter. (USBR Photograph No. P1166-500-4NA)

As a guide in their evaluations of phreatophyte water losses, the Bureau of Reclamation contracted the Rocky Mountain Forest and Range Experiment Station to prepare an extensive abstract bibliography of evapotranspiration. The report was furnished the Bureau in 1969. This report was extended, brought up to date, and published by the Department of Agriculture (Horton 1973), with the cooperation of the Bureau and the U.S. Geological Survey.

The extensive material gathered by various agencies to produce the above reports accumulated in a library sponsored by the Phreatophyte Subcommittee and maintained by the U.S. Forest Service. It is now housed at the School of Renewable Natural Resources, University of Arizona, Tucson, where it will be cataloged and placed in a retrieval system for maximum availability.

Research Projects: Robinson (1964) in his summary of Phreatophyte Research in the western states from March 1959 to July 1964 describes 48 projects, over 30 of them cooperative projects with two or more agencies involved. Outstanding among the long-term studies are the evapotranspirometers built at Buckeye, Yuma, and Humboldt River, Nevada, by the USGS and the Bureau of Reclamation (all described above). An example of the short-term studies is the root plow demonstration at Arlington, Arizona, where this machine was used for the first time on saltcedar. The cooperators included the Arizona Game and Fish Department; Corps of Engineers, U.S. Army; Bureau of Reclamation; Caterpillar Tractor Co.; and two branches of the U.S. Forest Service, Region 3 and the Rocky Mountain Station (Horton 1960).

An extensive cooperative study on the wildlife of the Colorado River phreatophyte flood plain by the Department of Zoology, Arizona State University, Tempe, is supported at present by the Bureau of Reclamation.

Conclusion: The information gained by the above projects added to that gained by actual field experience and other workers in related fields is sufficient to set down tentative management approaches and some very necessary restraints.

MANAGEMENT APPROACHES

The development of optimum management plans for the alluvial flood plains and riparian reaches of Arizona is complicated not only by the great variety of environmental situations but also by the many conflicting demands on the various resources. It must be borne in mind that the optimum management plan for any specific area can be developed only after all resources and all those interested in these resources are considered.

For management purposes, the flood plains can be separated into four ground-water level zones that control the vegetation structure. Although soil texture and salinity are also important factors, the relationships of soil characteristics to vegetation cover of the

flood plains are not precisely known; thus management, at present, must be determined primarily by the existing vegetation and knowledge of water-table depth. The riparian reaches can be separated by altitude and by species dominance for management purposes.

The four flood-plain zones are not precisely separated by water-table depth but there are specific differences between the zones which affect management practices. Due to the abundance of saltcedar, this species is used as practical means of separating the zones.

Flood-Plain Zone 1
(Very shallow water table--0-4 feet)

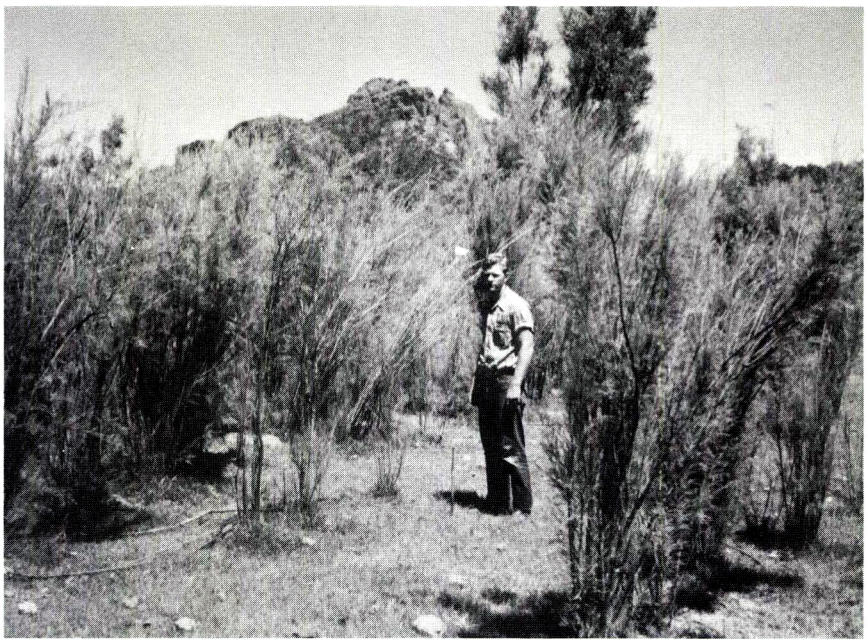
This zone can be recognized easily by the dwarfed and multistemmed saltcedar and the vigorous Bermudagrass or saltgrass cover. No specific depth can be given but it is generally about 3 to 4 feet or less. Along many streams, this particular zone is not developed because the streambanks rise quickly several feet above the water's edge and large saltcedars occupy this area. Before storage dams were built, this zone along major rivers was frequently altered by floods. Cottonwoods, willows, and other trees grew in the wider or more protected areas. Shrubs, such as seepwillow, would invade sandbars and the more sandy areas. Much of the area would be covered by grass and other herbaceous species after the immediate flood effects had disappeared. After the construction of dams, removal of trees by pioneers, and later the invasion of saltcedar, the zone developed into an open grass-saltcedar association.

Grazing and flood passageways would, in most cases, be a practical use of the zone. Water saving would be small if the saltcedar is removed. Wildlife use before treatment is minimal because the shrubs are not high enough for nesting purposes. After removal of the shrubs, waterfowl would find food in the grassy areas.

Shrubs could be cut periodically with a rotary mower or by other means. Grazing would tend to keep them under sufficient control to minimize future maintenance.

If the water table is lowered by shifting the low-flow channel or by increased pumping, the saltcedar will grow vigorously and decrease or even eliminate the grasses. This happened along the Salt River east of Granite Reef Dam where the Rocky Mountain Station established an experimental area in 1957. At that time, the cover of saltcedar and grass was a definite Zone 1 type. The change of river location in 1965 lowered the water-table depth from an average of 1 to 4 feet down to 7 feet or below. The result has been a rapid growth of the stunted saltcedar and almost entire elimination of the associated grass. Arrowweed has also increased.

Conclusion: Zone 1 can usually be managed for grazing and flood control without expecting any appreciable water savings if saltcedar is removed. Use by wildlife might be increased. If the water table in Zone 1 areas is lowered, Zone 2 or 3 conditions would be expected.



Flood-plain Zone 1. Open saltcedar and Bermudagrass cover growing where the water table is very close to the surface along the Salt River in Arizona east of Granite Reef Dam. (U.S. Forest Service Photograph No. JSH 125)

Flood-plain Zone 1. Saltcedar and seepwillow growing in a thin stand with Bermudagrass in the openings. Ground water is very close to the surface in this area of flood-plain Zone 1 along the Salt River east of Granite Reef Dam. (U.S. Forest Service Photograph No. JSH 999)

Flood-Plain Zone 2
(Shallow water table--4-8 feet)

The water table is shallow enough in this zone to be readily available to the roots of any established grass, but not so shallow as to restrict growth of saltcedar. Probably the depth would be roughly between 4 and 8 feet, depending on soil characteristics.

Clearing of saltcedar and other woody species would definitely save water. But many conflicts have developed for this zone. Saltcedar stands are often desirable for wildlife purposes or, in some areas, as a haven for bees. Where saltcedar is removed, the water thus saved would usually be allowed to increase riverflow an unknown amount for offsite use. In some areas, such as parts of Arizona, where legal restrictions allow development of water, on-site use of salvaged water could be directed to beneficial resources such as grazing areas or winter food for migratory waterfowl or summer-maturing grain for doves.

The habit of the white-winged dove to nest in colonies even in uniform cover, would, it seems, allow clearing of a portion of the saltcedar without appreciably affecting the dove population. As the bird's dependence on agricultural crops seems to be a more determining factor in its numbers than nesting space, provision in many areas must be made to supplement needed food to maintain the desired density of this species.

Fires threaten saltcedar areas. Breaking the heavy stands into blocks would make wildfires easier to control and reduce acreage of destroyed habitat.

Conclusions: Successful vegetation management would be fairly easy due to the relatively shallow water table. Where saltcedar is needed for wildlife or bees, strips or patches could be cleared to reduce water losses and to provide increased grass for other resource use as well as to improve flood control.

Flood-Plain Zone 3
(Medium water table--8-20 feet)

It is in this zone that the greatest water savings could be obtained by the removal of phreatophyte cover. Practically all of the water consumed by a heavy stand of saltcedar over a water table even as deep as 15 to 20 feet below the surface would be available for salvage if the stand was cleared. The clearing would either raise the water table, make more water available for pumping, or increase ground-water flow. Many water salvage programs have been designed for this zone.

Unfortunately this zone also presents serious problems if the saltcedar is removed for water salvage. Inasmuch as the water table is too deep for the establishment of Bermudagrass or other species so often found in the shallower water-table areas, the vegetation must be a desert type able to survive on the annual rainfall. In some cases this is not sufficient to provide a suitable vegetation cover to protect the soil surface

Flood-plain Zone 2. Saltcedar growing on the flood plain of the Gila River near Safford, Arizona. (U.S. Forest Service Photograph No. C 13)

Aerial view of the Gila River flood plain near Buckeye, Arizona, shows typical development of dense saltcedar Zones 2 and 3 with open stands of Zone 4 along edges of the flood plain, such as in the right center. (U.S. Geological Survey Photograph No. W58-144)

from wind erosion and from an unesthetic appearance. Many desert species, such as Atriplex, would provide a cover for wildlife and reduce wind erosion if they could be established successfully.

Where it is desirable to clear areas for water savings, strips or blocks of untouched saltcedar may need to be left for wind-erosion control and for wildlife. If water rights are available, part of the water saved by the removal of saltcedar could be used for irrigation to establish and maintain a stand of vegetation for site protection or other resource use, such as wildlife food.

Conclusion: Much research is needed in this zone to determine the management practices which best utilize all potentials of the site and to develop methods of achieving these objectives. Emphasis should be on possible replacement cover.

Flood-Plain Zone 4
(Deep water table–below 20 feet)

Though roots of mesquite and other desert trees may penetrate down to deeper layers than saltcedar, we have no information on the relative depths of root penetration or on the depths to which saltcedar will be able to extract water. Undoubtedly there is no definite demarcation between this and the other zones; the 20-foot figure is only a rough approximation. Scattered individuals of saltcedar do grow in alluvial soils that do not receive moisture other than the annual rainfall or floods. The shrubs are very widely spaced and become dormant during the drier periods but, when rejuvenated by rain or floods, will grow rapidly during the growing season.

Reducing the water table from a Zone 3 to Zone 4 will kill a large percentage of the saltcedar in a dense stand. Much of the Salt River flood plain through the Tempe and Phoenix area has been changed to this open tamarisk stand. It is far from esthetic and is not used by nesting doves, though quail and other birds may occupy the denser shrubby areas.

No water salvage could be expected by clearing.

Conclusion: Management of these desert areas will be quite limited, unless they are close to urban development or have irrigation rights.

Streams below 3,500 Feet

At elevations below 3,500 feet in Arizona, particularly on the wide flood plains of ephemeral streams and arroyos where deep alluvium occurs and ground water is generally less than about 20 feet, deep-rooted trees and shrubs exist and depend on the subterranean water throughout the growing season. Depending on the porosity of the alluvium, annual recharge, size of the aquifer, and the density of vegetation, this reservoir of ground water will be depleted by evapotranspiration each growing season; streamflow from winter

Mountain riparian vegetation, principally Arizona alders, growing along a flowing stream, Workman Creek. (U.S. Forest Service Photograph No. 152230)

Alders and other riparian species lining Oak Creek near Sedona, Arizona. (U.S. Forest Service Photograph No. JSH 307)

precipitation sometimes, but not always, replenishes the water lost to evapotranspiration. Obviously the removal of the trees and shrubs would eliminate much of the summer transpiration loss.

Conclusions: Present uses of this vegetation zone by livestock for shade and some food; food and cover for small birds and mammals; and use by campers, picnickers, and small-game hunters (particularly during the cool winter months) should be considered before vegetation removal for water-yield increases are initiated.

Streams between 3,500 and 7,000 Feet

The streams in this elevation zone may be: (1) permanently flowing fishing streams with a stand of such riparian species as Arizona alder (Alnus oblongifolia); (2) ephemeral with water flowing for only portions of the year usually supporting sycamores and associates; and (3) cottonwood on the wider alluvial flood plains (this type is discussed in the next section). These zones receive some of the heaviest recreational use in the Southwest. Therefore, in the eyes of the general public, water salvage would be undertaken only if recreation values are not impaired. However, carefully planned selective tree thinning and removal of undergrowth could improve esthetic appearances, recreation values, and reduce flood hazards. Water savings from such thinning treatments are not known because of lack of actual experimentation but, in general, vegetation removal of at least 40 percent has been necessary to cause significant water-yield increases on watersheds. Neither is the extent of losses or gains to wildlife food and habitat known as a result of selective thinning. Recreation use would increase if the area is accessible by nearby roads. In high-density recreational areas where flooding could cause loss of life or severe property damage, vegetation thinning for flood control may be necessary but this should not be so severe as to destroy other on-site uses of the streams. Total riparian vegetation eradication for water-yield increases can rarely be recommended because of loss of actual and potential recreation uses.

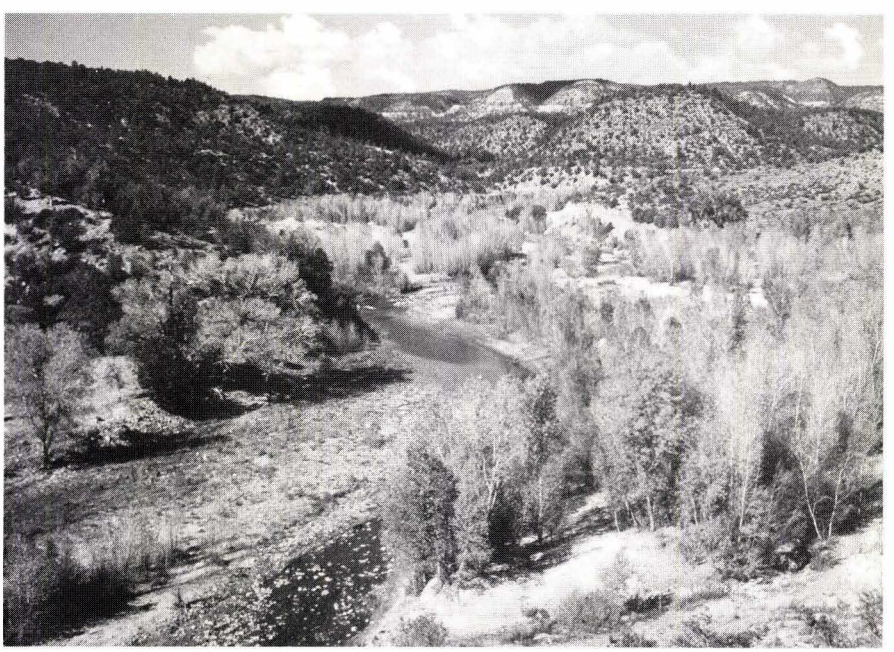
Treatment of chaparral or other vegetation types on the slopes of small tributaries of major channels offers a distinct opportunity to increase water yields. This water flow will increase the riparian nature of some ephemeral streams and will increase recreation potential as well as produce additional streamflow for other uses. Watershed management for development of on-site use may become an important practice in the future.

Conclusion: Management of these streams should always be correlated with management of the entire watershed in these elevations. On-site use by people in this zone is important; however, both on-site use and an increase of water by vegetation removal could often be accomplished with carefully planned vegetation manipulation.

Cottonwood Management

Cottonwood, common in the phreatophyte and riparian zone of the upper desert and chaparral areas, once dominated most of the streams and flood plains of the Southwest, even along the rivers where saltcedar now thrives. It is probable, however, that it did

Sycamores growing along Sycamore Creek near Sunflower, Arizona. (U.S. Forest Service Photograph No. JSH 1001)



Cottonwoods growing along Carrizo Creek, Arizona. (U.S. Forest Service Photograph No. JSH 205)

not develop readily on the flood plains except in Zones 1 and 2, described above. Zone 3 might have had cottonwood if it originally developed under more favorable moisture conditions.

At the elevations where cottonwood now flourishes, indications are that complete removal of trees growing in a typical open stand would save 1.5 to 2.0 feet of water. No information is available on the amount saved if stands are only thinned or after other natural growth invades the streams but it is probable that at least 50 percent or more of the cover would have to be removed before there would be any appreciable savings of water.

Cottonwood stands adjacent to farmlands often clog the river channel and divert floodflows onto these lands or into other developments. Thus some tree and undergrowth cutting along a central channel should always be done to reduce flood hazards. These clearings would be useful both for recreational areas and to increase grazing.

In spite of these disadvantages, dense cottonwoods have important intangible values, such as the birdlife that thrives in these groves. In both southern New Mexico and southern Arizona, peripheral bird habitats lap into the United States from Sonora, Mexico. These are of great ornithological interest.

Conclusions: In the management of cottonwood areas, consideration should be given to the need to increase water supply and grazing use and to aid in flood control along with improvement of the area for wildlife, recreation, and esthetics. Such plans would probably call for some reduction in the tree stand. Birdlife seems to be reduced in proportion to the thinning and, therefore, care should be taken to preserve sufficient habitat areas for both game and nongame species. This may require special efforts to improve these wildlife habitats to encourage bird reproduction in these stands. Fortunately cottonwood trees grow rapidly and it is relatively easy to establish them wherever there is sufficient water.

Streams above 7,000 Feet

Little, if any, foreseeable change in present management practices is indicated on the high elevation mountain streams in the Southwest. Erosion and evapotranspiration are usually not severe along streams above 7,000 feet. Recreation use must be managed so as to prevent deterioration of the stream habitat. Erosion control where needed and maintenance of optimum fish habitats should have high priority in all management plans.

Section Conclusions: Optimum management of moist-site areas, whether dominated by saltcedar, cottonwood, or other riparian species, requires careful consideration of all factors of the environment and economic needs. Seldom are areas best managed by devoting the land to a single use, as compromise management will usually return the greatest total value.

FUTURE RESEARCH NEEDS

The above discussions of possible management approaches indicate that we do have extensive information about the moist-site zones. But, it also points out many unanswered questions. The Bureau of Reclamation in cooperation with the Agricultural Research Service (1972) prepared an excellent report urging development of future research studies, primarily to determine evapotranspiration losses. It summarizes the 1951 objectives of the original Phreatophyte Subcommittee, the report of the USDA Research Task Force (1961), and the report that Horton (1969) prepared for the Bureau of Reclamation as an introduction to the original Abstract Bibliography on Evapotranspiration. Emphasis in all of these was on the need to more accurately determine water losses from vegetation. The Bureau report points out that little specific information has been added recently on the actual water losses from phreatophyte vegetation. However, recent analyses tend to show that the data are far less contradictory than have been claimed. Information from the Gila River reach study and the Bernardo and Buckeye tanks, added to the data from earlier studies, give a reasonable picture of what to expect in the matter of water losses and the amount to be gained by clearing. All these data emphasize that phreatophytes use a large amount of water and a sizable percentage can be saved by reducing the vegetation cover.

The problem now lies in the correlation of these savings in water with the values of other resources of the phreatophyte and riparian vegetation. Our research needs, therefore, are centered in the determination of the effects of various treatments upon each and every resource and upon the species of plants and animals involved. The Bureau report outlines a specific approach to solving our needs; its points are considered below.

While determination of more refined information on water losses in relation to species and environment should be continued, this aspect is overshadowed by the need for information about the other resources on which to base optimum compromise management practices.

Unfortunately, several agencies which were active in the past, have discontinued their studies. The U.S. Geological Survey has completed its Gila River reach study. The Forest Service has discontinued active research on moist-site vegetation at Tempe and the Agricultural Research Service has closed its Laboratory at Los Lunas, New Mexico. The Bureau of Reclamation continues the Research Laboratory at Denver, Colorado, and this agency is actively sponsoring research studies on a cooperative basis.

Much more needs to be done in order to develop positive programs for optimum management of phreatophyte and riparian sites. There have been many excellent suggestions offered by various members of the Vegetation Management Subcommittee. Most of them are included in the following outline. (These are not listed necessarily in order of importance.)

1. Survey pertinent existing flood-plain clearings to determine:

   A. Any further effect on water losses such as might be determined by ground-water levels, etc.

   B. Vegetation regrowth. What species have invaded the cleared areas?

   C. Wildlife response. This would be particularly important where the clearings were in strips or patches.

   D. In summary, this would be a review of past work to determine what information could be gathered which has not been reported already.

2. Establish new partial clearings to determine effects upon all resources. Careful studies should be included to measure responses in:

   A. Ground water.

   B. Wind erosion.

   C. Vegetation return both natural and artificial.

   D. Wildlife.

3. The same types of studies need to be carried on in the riparian zones:

   A. Effect on water losses, including water temperature.

   B. Bank erosion.

   C. Vegetation response.

   D. Wildlife, including aquatic species.

4. The fundamental aspects of water losses, both transpiration and evaporation, must be emphasized:

   A. Large-scale methods should be stressed, including approaches such as laser beams and infrared color photography.

   B. Measurement of evapotranspiration losses from individual plants or groups of plants needs to be continued and increased.

   C. Research on the transpiration processes and the physiology of moist-site species which relate to water losses should be intensified; this would include the effect of antitranspirants.

5. Continued research in control activities. How should these clearings or activities mentioned above be brought about economically and with the least damage to the environment?

   A. Types of chemicals and their application. No overall review of the present knowledge about chemical control of saltcedar is available in the literature.

   B. Mechanical methods.

   C. Antitranspirants.

6. Ecological studies.

   A. Specific information on the principal species is either not sufficiently complete or not readily available. Tamarisk ecology has been thoroughly studied but the information has not yet been accumulated in one summary publication. What is known about mesquite has been published as an abstract bibliography (Schuster 1969), but more work needs to be done to bring this up to date and similar reports prepared for other species.

   B. Replacement species, either the introduction of new species or the favoring of natives, need to be thoroughly studied to develop methods of establishing a suitable and usable cover after clearing, especially in drier zones.

Conclusions: Development of such a program will require the cooperation of the research and action agencies. This, in the past, has often been accomplished through the Phreatophyte Subcommittee contacts and, therefore, could best be brought about now with activities of the present Vegetation Management Subcommittee. In addition to the needs of the moist-site zones, many similar problems could be studied for other vegetation zones and solutions developed. For instance, the present subcommittee has undertaken to correlate activities concerning the strip-mine problems, especially revegetation. Research needed in these other zones would follow much the same pattern as for the moist-site areas. A full report evaluating these needs and the relationship of the Vegetation Management Subcommittee to such future activities should be prepared.

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